SOME CAUSES OF THE DECLINE IN RANGE AND ABUNDANCE OF NATIVE FISH IN THE MURRAY-DARLING RIVER SYSTEM

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ABSTRACT: Various authors have reported a decline in the range and abundance of many native fish in the Murray-Darling System. Several factors may have contributed to this decline. Hydro-electric, irrigation and water conservation schemes have altered the flow and thermal regimes of many rivers, thereby adversely affecting the reproductive ability of those native fish which require specific minimum water temperatures and floods as triggering mechanisms for spawning and subsequent survival of eggs and young. Dams act also as physical barriers to the movements of fish. Forestry and farming practices and land clearing in the upper reaches of the system have caused changes in the pattern of run-off, leading to increased siltation. This has probably reduced the reproductive success of fish which lay adhesive eggs on the substrate, and has caused also the filling in of previously deep holes, thereby removing part of the habitat of fish such as cod. Desnagging and channelization of rivers have removed native fish cover and spawning sites. Fish kills have been caused by heavy metal pollution and by the agricultural application of compounds such as Lindane, Aqualin and Endrin, and many fish have been found to contain sub-lethal amounts of insecticide residues. Introduced trout have fragmented the ranges of some galaxiids and have probably had adverse effects on trout cod, Macquarie perch and blackfish. Other introduced fish have probably adversely affected the native fish fauna, but information on the effects of introduced fish on native fish is usually anecdotal and fragmentary. Considerable further work is required on the factors affecting the range and abundance of native fish, and the results of this work should be used for determining future river management policies.

INTRODUCTION

Excluding essentially marine species which are sometimes found in the lower reaches of the Murray, there are 26 species of native fish in the Murray-Darling River System (Table 1). These fish have evolved in an unpredictable and widely-fluctuating environment in which large natural fluctuations in population size are to be expected (Mackay 1973). However, Macquarie perch and trout cod are now rare and seriously threatened with extinction, and the distribution and/or abundance of catfish, golden perch, Murray cod and blackfish have been reduced as a result of man's activities (Williams 1967, J. S. Lake 1976b, 1971, Berra 1974). The distribution and abundance of many of the smaller species, such as galaxiids, have also been affected (Pollard & Scott 1966, J. Frankenberg 1971), but little is known about the biology or the past distribution of many of these species.

There are many ways in which man's activities have affected the distribution and abundance of native fish. Some have resulted in direct fish kills, but, in most instances, the effects have been indirect or of a sub-lethal and chronic nature. Because our knowledge of this fauna is so poor we can, in many instances, only speculate on the effects that man's past activities may have had on the native fish.

HYDRO-ELECTRIC, IRRIGATION AND WATER CONSERVATION SCHEMES

At present, about 10% of the world's total stream flow is regulated by man (Croome *et al.* 1976). In the Murray-Darling Basin, extensive hydro-electric, irrigation and water conservation schemes have resulted in the regulation of the flow of many rivers, and nearly half the mean natural flow of the system is now drawn off for irrigation and urban use (Frith 1973). The Murray itself is regulated by weirs and dams at intervals from the Hume Dam

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TABLE 1
NATIVE FISH OF THE MURRAY-DARLING RIVER SYSTEM

Modified from J.S. Lake (1975). The taxonomy of some of the groups, e.g. the Galaxiidae, is presently under review.

Family	*Species*	*Common name*
Petromyzontidae	*Mordacia mordax* (Richardson)	Short-headed lamprey
Clupeidae	*Fluvialosa richardsoni* (Castelnau)	Bony bream
Retropinnidae	*Retropinna semoni* (Weber)	Australian smelt
Galaxiidae	*Galaxias maculatus* (Jenyns)	Common galaxias
	Galaxias planiceps Macleay	Flat-headed galaxias
	Galaxias findlayi Macleay	Kosciusko galaxias
	Galaxias olidus Günther	Common inland galaxias
	Galaxias oconnori Ogilby	Queensland mountain galaxias
	Galaxias rostratus Klunzinger	Beaked galaxias
Plotosidae	*Tandanus tandanus* Mitchell	Freshwater catfish
Melanotaeniidae	*Nematocentrus fluviatilis* (Castelnau)	Rainbow fish
Atherinidae	*Craterocephalus fluviatilis* McCulloch	Hardyhead
Centropomidae	*Ambassis castelnaui* (McLeay)	Western chanda perch
Percichthyidae	*Macquaria australasica* Cuvier and Valenciennes	Macquarie perch
	Plectroplites ambiguus (Richardson)	Golden perch
	Maccullochella peeli (Mitchell)	Murray cod
	Maccullochella macquariensis (Cuvier and Valenciennes)	Trout cod
Teraponidae	*Madigania unicolor* (Günther)	Spangled perch
	Bidyanus bidyanus (Mitchell)	Silver perch
Kuhliidae	*Nannoperca australis* Günther	Southern pigmy perch
Gadopsidae	*Gadopsis marmoratus* Richardson	River blackfish
Eleotridae	*Philypnodon grandiceps* (Krefft)	Big-headed gudgeon
	Mogurnda mogurnda (Richardson)	Purple-spotted gudgeon
	Hypseleotris klunzingeri Ogilby	Western carp gudgeon
Mugilidae	*Mugil cephalus* Linnaeus	Mullet
Bovichthyidae	*Pseudophrites urvilli* (Cuvier and Valenciennes)	Congoli

upstream of Albury-Wodonga to the saltwater barrage on Lake Alexandrina at its mouth, a distance of 2,200 km. The principal water storages (Table 2) are in the headwaters of the system. In summer, water is released from the dams at a fairly constant rate for irrigation purposes. Irrigation flows cease in autumn and the dams begin to store the normal flows of winter and spring. Generally, the uncontrolled river was high, cool, turbid and fast flowing in spring and early summer and these conditions changed gradually until, by the end of summer, the waters were low, warm, slow flowing and clear (Butcher 1967). Thus, the effects of dams are to reverse the natural pattern of water flow and to reduce the incidence of floods or, at least, cause the flattening out of successive flood peaks (Williams 1967, Wharton 1969). Since water is lost by evaporation from the storage reservoirs, dams also decrease the total runoff.

Because outflow water is invariably taken from near the bottom of a dam, in summer it is much colder than the inflow water, and it must flow for

TABLE 2
PRINCIPAL STORAGES IN THE MURRAY-DARLING DRAINAGE BASIN

Modified from Australian Water Resources Council (1976)

I = *Irrigation*; H= *Hydro-electric*; W = *Water Supply*; F = *Flood Mitigation*

Storage	*River*	*Gross capacity ($m^3 \times 10^6$)*	*Purpose*
Dartmouth*	Mitta Mitta	3700	I, H
Eildon	Goulburn	3390	I, H
Hume	Murray	3038	I, H
Menindee Lakes	Darling	1794	I, W
Burrendong	Macquarie	1680	I, F
Blowering	Tumut	1628	I, H
Copeton	Gwydir	1364	I
Wyangala	Lachlan	1220	I
Burrinjuck	Murrumbidgee	1026	I

* *under construction*

many kilometres downstream before reaching the temperature of the inflow water. For example, at Eildon Reservoir the outflow water comes from 52 m below full supply level, and summer temperatures in the Goulburn River many kilometres below the dam are 10-15°C lower than those of the inflow water (Williams 1967).

These changes in both flow and thermal regimes have had a marked effect on native fish, many of which require specific minimum water temperatures and floods as triggering mechanisms for spawning and the subsequent survival of eggs and young. J. S. Lake (1967a) found that golden perch and silver perch spawn at water temperatures above 23°C provided there is an accompanying rise in water level; Murray cod were found to spawn at 20°C, western carp gudgeon at 22.5°C and catfish at 24°C. Llewellyn (1973, 1974) found that spangled perch spawn at water temperatures of 20° (bottom) to 26°C (surface), and southern pigmy perch at 19.3°-21°C. Flooding helps to induce spawning of spangled perch but is not essential. In the Eildon Reservoir and its inflowing rivers, Macquarie perch were found to require a water temperature of 16.5°C before spawning movements and spawning occurred (Wharton 1968, Cadwallader & Rogan 1977). The colder water and/or the timing and extent of flooding has adversely affected the ability of these species to reproduce. According to J. S. Lake (1975) the Murray from Albury to Euston and beyond now rarely reaches a temperature high enough to induce golden perch to spawn.

Flooding provides ideal conditions for the pelagic eggs of golden perch and silver perch. Such eggs, which are more common in marine fish, are not suited to fast water currents but thrive in relatively tranquil flood-spread waters.

The gradual elimination of the great anabranch or backwater systems of the Murray and its tributaries by water control schemes (including the construction of levee banks which effectively reduce the floodplain area) has reduced the extent of waters which previously provided the necessary space and food for the young of many fish species. In the Murray-Darling River System good year classes of fish such as Murray cod have been produced only following extensive floods at spawning time (J. S. Lake 1971).

Dams and weirs act as physical barriers to the movements of fish. Data on the movements of native fish, particularly golden perch, in the Murray-Darling System have been derived from long-term tagging programmes undertaken by the State fisheries agencies of New South Wales, Victoria and South Australia. Llewellyn (1968) reported that golden perch moved upstream as much as 1,000 km in 163 days, and that upstream movement was closely related to river height (Fig. 1). Movement of fish may also be influenced by temperature, since fish moved less when floods occurred in winter. Reynolds (1976) also reported extensive movements by tagged golden perch (Fig. 2); most of these long-distance upstream movements were recorded from fish released towards the end of September 1975, just before the 1975-76 flood broke over the river banks. It appeared that the massive migration was a result of the flood, but it is not known whether spawning requirements, food requirements or an alteration in water quality triggered the migration. In the past, large numbers of golden perch moving downstream have been taken in drum nets in June and July, when the water has been low (Cadwallader 1977). Although not necessarily directly related to spawning, the upstream movements ensure that spawning occurs upstream of the areas occupied at other times of the year and thereby compensate for any downstream displacement of eggs and recently hatched fish. In the Murray, the abundance of golden perch above Yarrawonga Weir has been greatly reduced and they are very rare as far downstream as Torrumbarry Weir (Lake 1975).

Fishways and fish ladders provide continuity between the fish populations above and below dams, but there are only two such structures in operation on the Murray-Darling River System (Wharton 1969). Their importance to fish

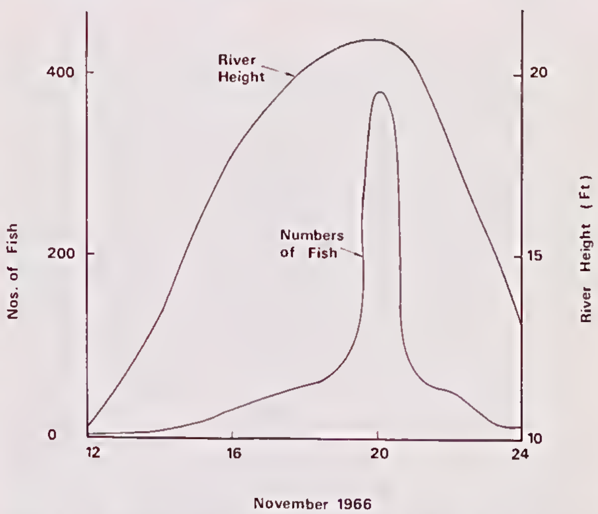

Fig. 1 — Relationship between river height and number of upstream-moving fish, mainly golden perch, taken in drum nets in the Murrumbidgee River in November 1966. After Llewellyn (1968).

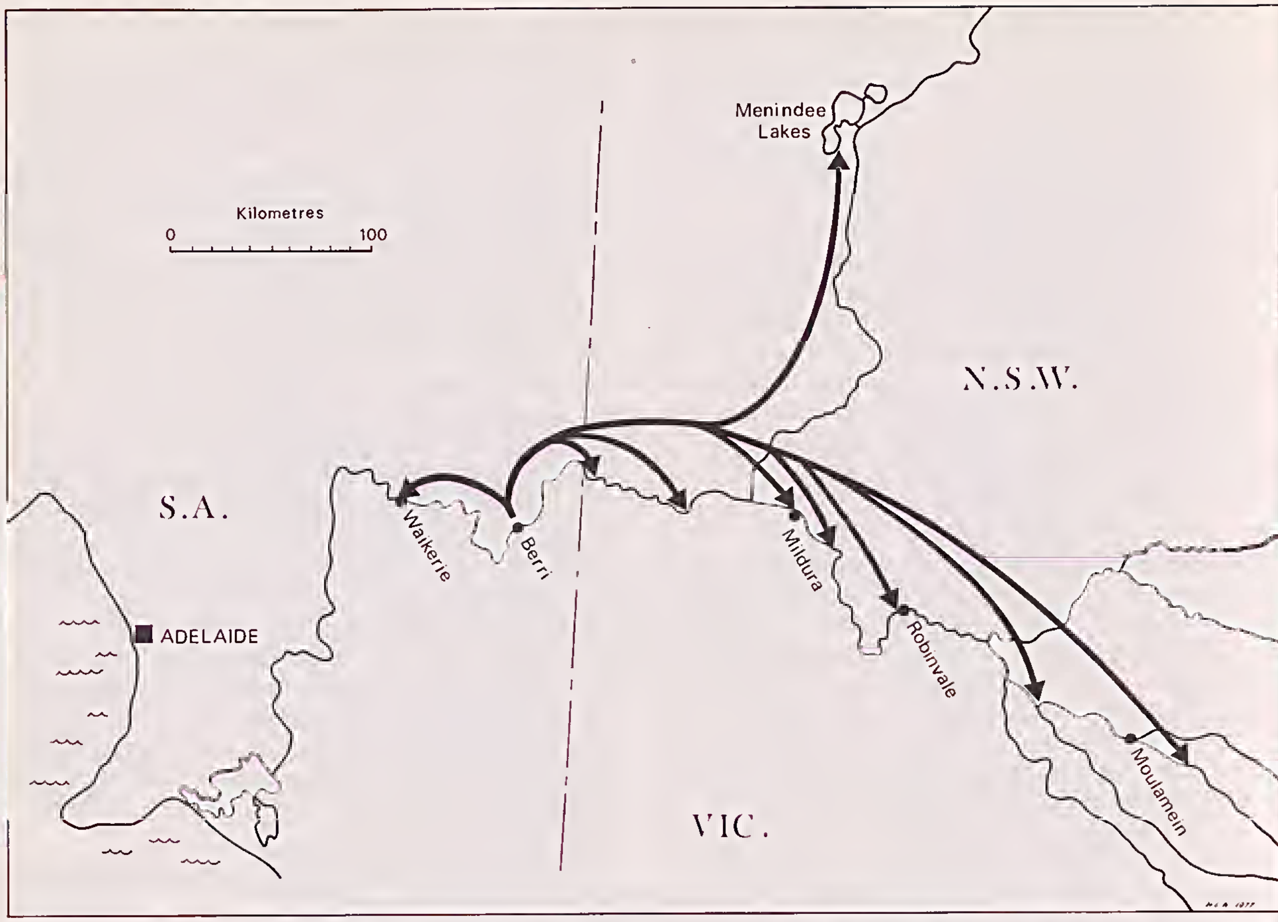

FIG. 2 — Movements of golden perch tagged and released in the Murray River at Berri, South Australia. After Reynolds (1976).

movements is indicated by the numbers of native fish which have been recorded passing through the Euston-Robinvale fish ladder (Fig. 3). The design and efficiency of such structures, particularly for large dams, depends on detailed knowledge of the swimming capabilities and behaviour of the migrating fish. This knowledge is not yet available for Australian native fish. Furthermore, fishways or fish ladders for native fish are of little use unless there are discharges of the appropriate temperature and volume to induce movements. The problem of discharging water of a particular temperature can be overcome to some extent by the use of multi-level offtakes on dams (so that water can be drawn from particular levels), but without the increased flow, the warmer water by itself may be insufficient to stimulate the spawning of fish such as golden perch and silver perch. However, as pointed out by Frith (1973), it should be possible to release water at times appropriate to fish breeding and then retrieve it downstream to be used for other purposes.

Sudden fluctuations in water level caused by irrigation or power generation requirements may have disastrous effects on fish such as western carp gudgeon, which spawn in shallow water over grasses and twigs (Lake 1975). The sudden release of water can displace eggs and young fish to unfavourable situations and a sudden reduction in discharge can leave eggs stranded above water.

As pointed out by Ridley & Steel (1975), a marked reduction in maximum flows and the consequent prevention of flood-time scouring has often led to an increase in the occurrence of macrophytes downstream from large dams. Although the establishment of macrophytes in many backwaters of the Murray-Darling System may not have directly affected the native fish species, the abundant water weeds and reeds in some areas have provided ideal spawning grounds for introduced fish such as European perch and tench (Cadwallader 1977).

The presence of a dam usually increases the plankton content of the water downstream from the storage, and the benthic fauna is also affected by the changed flow and thermal regimes. Reservoirs also act as settling basins and reduce the turbidity of the water, although some management practices may increase turbidity by the discharge of turbid layers from the reservoir. Water downstream from the dam may also be chemically unusual and contain large quantities of bacteria as well as moribund algae from the hypolimnion (Fraser 1972, Hynes 1972). The effects of such changes on the fish fauna of the Murray-Darling System have been overshadowed by the effects of changed flow and thermal regimes, and have yet to be evaluated.

The large storage reservoirs are usually deep and cold, and generally have lower area-volume ratios than natural lakes of comparable size (Williams 1973). The lack of fringing vegetation in most of the artificial reservoirs is almost certainly due to the fluctuations of the level of the stored water. This lack of vegetation affects the composition and productivity of the associated invertebrate fauna (Williams 1967) and, consequently, the composition and productivity of the fish fauna.

As new storages are filled they flood the surrounding land, and the rotting vegetation liberates abundant nutrients. This leads to an explosive development of fish food. The fish that are able to take advantage of the abundant food available at this time and those that can spawn under the new conditions will flourish. Eventually the productivity of the newly-formed lake will fall and the fishing will inevitably decline (Elder 1965, Lowe-McConnell 1975). At best, in the Murray-Darling Basin, only residual populations of native fish exist in impounded waters, which invariably are dominated by introduced species (Butcher 1967). For example, Macquarie perch were once abundant in Eildon Reservoir, but they are now recorded only rarely from the reservoir and its inflowing rivers; the fish fauna of the reservoir now consists predominantly of introduced European perch, goldfish and trout (Cadwallader & Rogan 1977). Following the construction of dams, introduced trout now occur at relatively low altitudes and survive the years of exceptional heat and drought because of the cooler water present in the depths of the large reservoirs (J. S. Lake 1975). Furthermore, trout are able to survive downstream from the reservoirs because of the cold water released from the dams in summer. Impoundments throughout south-eastern Australia have provided additional trout waters and occasionally, e.g. as in the case of Lake Eucumbene (Tilzey 1972), support flourishing fisheries. The effects of trout on the native fish fauna are discussed later.

Another aspect of water management practices that affects native fish is the diversion of rivers from one watershed to another. An example of this is the diversion of the Snowy River from the southeast coastal drainage system to the Murray-Darling River System (Australian Water Resources Council 1976). Such diversions change zoogeographic boundaries and modify natural systems (Butcher 1967). The fisheries implications of water transfers between catchments have recently (1976) been discussed by a joint study group of the Ministry of Agriculture, Fisheries and Food and the National Water Council (U.K.), which concluded that the greatest risk of damage appears to be in producing highly unstable ecological conditions (by transfer of water of different physical and chemical characteristics, transfer of pollutants, transfer of fish and eggs, etc.) and in the widespread dissemination of fish diseases.

FIG.3 — Monthly variation in the upstream movements of silver perch, golden perch, Murray cod and Macquarie perch as indicated by fish passing through the fish ladder on weir and lock no. 15 (Euston-Robinvale) on the Murray River between 28 May 1938 and 7 November 1942. The histogram for each species represents the proportion of fish passing through the ladder each month as a percentage of the total number of fish of that species passing through the ladder between May 1938 and November 1942. After Cadwallader (1977).

LAND CLEARING, FARMING AND FORESTRY PRACTICE

Clearing of land and over-grazing by stock cause changes in the pattern of run-off and lead to increased siltation (Hewlett & Helvey 1970, Bayly & Williams 1973). The removal of trees from large areas of the catchments of many Victorian streams has greatly increased the difference between the maximum winter and minimum summer flows, so that, in extreme cases, originally perennial streams are now intermittent, with obvious consequences for the fish stocks. Burning-off and uncontrolled fires also have important effects. The increase in run-off after a fire has been estimated at about 50%, and the siltation rate is also greatly increased. For example, in the 12 months after the 1939 bushfires the siltation rate in the Eildon Reservoir was greater than that for the preceding 16 years (Williams 1967). Though fires are not a human innovation, there is evidence that they were much less frequent before European man arrived in Australia. Bank erosion caused by poor farming practices (e.g. allowing stock direct access to streams) has led to changes in the general character of many streams, changing them from narrow, clear waters with deep holes to wide, shallow, muddy tracts (Wharton 1969).

Siltation has a number of direct and indirect effects on the native fish fauna, particularly in the upper reaches of the Murray-Darling System. Fish such as Macquarie perch, which lay adhesive eggs on the substrate (Wharton 1968, Cadwallader & Rogan 1977), have probably been the most directly affected by increased siltation. Erosion silt also fills in deep holes, thereby destroying parts of the habitat of Macquarie perch and cod. Apart from blanketing the stream bottom, silt screens out light (thus interfering with the feeding of those fish which feed primarily by sight), changes heat radiation and causes the retention of organic material and other substances which may create unfavourable conditions on the substrate (Ellis 1936). Thus, the composition of the benthic flora and fauna is altered (Cordone & Kelley 1961), with consequent adverse effects on the food chains of the fish.

Recent work in the northern hemisphere has clearly indicated the relation between the nature of the valley through which a stream flows and the productivity of the stream. Upland streams are basically heterotrophic and derive all or most of their energy from organic material elaborated in the watershed (Cummins 1975, Hynes 1975), so that clearing of vegetation in the catchment area changes the productivity of a stream by reducing the input of organic material. As pointed out by P. S. Lake (1976), clear-felling, a major harvesting method of modern intensive forestry carried out in the forested catchments of many streams in southeastern Australia, is probably having extremely damaging effects on the structure and function of stream ecosystems. In addition to reducing the input of organic material, clearing of land right to the edge of streams also increases the amount of sunlight reaching the water, thereby causing an increase in water temperature, which, in turn, influences the levels of oxygen and solids dissolved in the water (Brown & Krygier 1970). Furthermore, the nitrate concentration of a stream flowing from a clear-felled watershed may rise to such an extent that algal blooms, usually rare in streams, may occur in summer (Burton & Likens 1973). Removal of native trees and planting of introduced trees such as pines may also affect the productivity of streams. The fauna of streams has evolved in conjunction with the surrounding terrestrial vegetation, so that the stream invertebrates are able to utilise efficiently the organic material derived from that vegetation. It may be assumed that in headwater streams of the Murray-Darling System the invertebrates are adapted to metabolise organic material from dry and wet sclerophyll eucalypt forests and it is likely that they cannot efficiently utilise organic material derived from a pine plantation (P. S. Lake 1976). In North Carolina, Woodall & Wallace (1972) compared the productivity of four streams, three with non-coniferous vegetation and one with the coniferous white pine (*Pinus strobus*) in their catchments, and found that the stream with the white pine in the catchment supported only one fifth to one half as much animal biomass as the other streams. Differences among the watersheds were attributed to different inputs of allochthonous material. These differences were found even in a part of the world where pines are found naturally and it was concluded that the results 'indicate that forest monoculture practices involving pine watersheds may seriously affect secondary production of aquatic invertebrates' with, no doubt, consequent adverse effects on fish production.

A more direct influence of bank-side vegetation on native stream-dwelling fish was found during a study (Cadwallader & Eden unpublished data) of the summer food of *Galaxias olidus* in streams of the Seven Creeks River System, which drains into the Goulburn River, in Victoria. Arthropods of terrestrial origin form a substantial part of the diet of these galaxiids, which feed in open water and readily take arthropods that fall or alight on the water surface. An examination of the stomach contents of 30 fish from each of ten sampling stations revealed that the incidence of terrestrial insects in the diet was closely related to the type and amount of bank-side vegetation, and was lowest in fish from areas where the native trees and understorey had been cleared.

'RIVER IMPROVEMENT'

'River improvement' schemes are aimed at controlling erosion, minimising the effects of flooding, and improving the water carrying capacity of streams. In Victoria in 1969, about 2,250 km of rivers and streams (this distance being divided almost equally between coastal streams and those flowing into the Murray) were subject to 'river improvement' (Wharton 1969) and today the areas under the control of river improvement trusts are even more extensive (Conservation Council of Victoria 1977). 'River improvement' activities imply physical modification of streams. They include desnagging of waterways to remove logs and other debris, the removal of standing trees which are likely to fall into rivers and, often, the straightening of a river to make it more like a channel. As pointed out by Rogan (1977), these activities take place without any overall planning or coordination and, in most cases, with little thought of the direct or indirect effects on the aquatic fauna.

The desnagging of rivers removes much of the available cover, particularly for fish such as blackfish which are frequently found amongst debris. Many North American studies, e.g. see those cited by Gunderson (1968), have demonstrated the importance of cover to fish; more fish invariably occur in those sections of river which have the most cover. Desnagging also reduces the number of potential native fish spawning sites. J. S. Lake (1967a) found Murray cod eggs adhering to the inside of a fibro-cement pipe in a pond at the New South Wales Inland Fisheries Research Station at Narrandera, and it seems likely that under natural conditions Murray cod lay eggs within or on logs or other debris on the river bed. This probably is true also for trout cod, which also have adhesive eggs (Cadwallader 1977). Developing blackfish eggs have been found in submerged hollow logs in a natural situation (Jackson 1978) and, although blackfish may also lay eggs beneath and between boulders, logs and other debris may provide the only egg deposition sites in soft-substrate situations. In addition, the removal of debris from river banks and flood plains reduces the number of potential spawning sites which may be used during floods or high-water conditions.

Channelization converts a meandering stream with alternating pools and runs into a straight ditch with continuous runs and high banks. The consequent negative effects on invertebrates and fish are widely recognised (see Schneberger & Funk 1971). One example of the effects of channelization on aquatic fauna is provided by the work of Moyle (1976a) in California. In this study it was found that the invertebrate biomass and the fish biomass in channelized sections of a stream were less than one third of the invertebrate biomass and the fish biomass in unchannelized sections. The invertebrate species composition of channelized and unchannelized sections was also different.

POLLUTION

Water pollution may be defined as 'a significant and deleterious change in the natural character of a water resulting from the addition of material or heat by man' (Williams 1969). The range of pollutants is vast (Bayly & Williams 1973, Connell 1974), but the main water-pollution problems in Australia relate to sewage, industrial effluents and salinity (Frith 1973). Jones (1964) reviewed the effects of river pollution on fish, with particular reference to North America and Europe, but, although there are some records of isolated fish kills produced by gross pollution, there is very little published material on the sub-lethal or otherwise long-term effects of pollution on the native fish of the Murray-Darling Basin.

The most comprehensive study of water pollution in the Murray-Darling Basin is probably that of Weatherley *et al.* (1967) on zinc pollution in the Molonglo River. At Captains Flat on the upper Molonglo River, zinc, copper and lead mining has resulted in extensive tailings, rich in zinc, being distributed for about 15 km along the river banks. Zinc entered the river from these tailings and from mine drainage water and caused the reduction or disappearance of whole components of the normal stream fauna (as judged by comparison with neighbouring streams) for about 40 km downstream. Molluscs, crustaceans, plecopterans and fish were very poorly represented in this stretch. Zinc not only poisons fish and their food organisms directly, but it also destroys the epilithic algae which serve to cement the substrate together. A marked instability of the substrate is characteristic of the badly polluted stretches of the river. P. S. Lake (1973) doubts whether the Molonglo River will ever adequately recover from the pollution and points out that, as a general rule, ecosystems that have been damaged by heavy metal pollution very rarely return to their original condition. It is significant that where the Queanbeyan River enters the Molonglo River there is a relatively normal flora and fauna because of the dilution of the polluted water.

Agricultural sprays have also taken their toll. Many of these sprays contain D.D.T. which under certain conditions is lethal to some fish in extremely low concentrations (Jones 1964). Such insecticides are a danger to fish even when used in sub-lethal concentrations because, as pointed out by Pollard & Scott (1966), fish food organisms can store insecticide residues and pass on large amounts to fish. In Victoria, Butcher (1965) reported that it had not been possible to find any freshwater fish which were entirely free of insecticide residues, despite the fact that collections were made in some very isolated areas. Fish from the Namoi region of New South Wales have also been found to contain from 0.1 to 3.3 ppm of D.D.T. residues (Connell 1974). The sub-lethal effects of pollutants are often subtle and may require long-term monitoring if they are to be understood. Kleerekoper (1976) has suggested that general locomotory behaviour and orientational response to environmental stimuli may be affected, with consequent adverse effects on predator-avoidance responses. Vigour, the ability to reproduce, and the development and survival of young fish may also be affected (Butcher 1965, Weis & Weis 1977).

Fish kills have occurred in Victoria after agricultural application of Lindane, Aqualin, and Endrin (Connell 1974). Some of these kills have occurred after the spraying of tobacco crops adjacent to streams (Butcher 1965). Several instances of fish mortality due to the use of insecticides to control mosquitos have been reported, and algacides used for clearing weeds from irrigation ditches have also caused fish kills (Pollard & Scott 1966).

Enormous fish kills occurred in the Murray River after the first releases of water from Hume Weir. These kills have been attributed to the large amounts of eucalyptus oil and ash carried downstream. The later use of copper sulphate (between 24 and 35.5 tons per summer between 1929 and 1934) to control algal growth in the weir also caused fish kills (Cadwallader 1977).

Some inland rivers were always to some extent saline, but since European settlement and the development of agriculture the salinity of some rivers has increased greatly (Bonython & Frith 1974). To date, there is no demonstrable evidence of any significant effect of salinity on the fish of the Murray-Darling Basin. Indeed, as pointed out by Butcher (1973), it is likely that during the course of their evolution many animals associated with the Murray have had to contend with large natural fluctuations in salinity. In a study of the occurrence of fish in saline lakes in Victoria, Chessman & Williams (1974) found that many native species, e.g. smelt, big-headed gudgeon, western carp gudgeon, pigmy perch, hardyhead and flat-headed galaxias, all of which also occur in the Murray-Darling System, can tolerate salinities greater than 3,000 ppm. In addition, the normally catadromous common galaxias, *Galaxias maculatus*, which occurs in the lower reaches of the Murray, has been found in waters with a salinity as high as about 49,000 ppm (Chessman & Williams 1975).

INTRODUCED FISH

There are nine self-maintaining species of introduced fish in the Murray-Darling Basin (Table 3). The history of their introduction and acclimatisation, dating back to 1864, has been reasonably well documented, e.g., see Nicols (1882), Wilson (1879), Dannevig (1904), Roughley (1951), Arentz (1966), Butcher (1967) and Weatherley and J. S. Lake (1967). In addition, Atlantic salmon, *Salmo salar* L., were recently liberated in the Goodradigbee drainage of Burrinjuk Dam (Francois 1965), but they do not appear to have established themselves and the New South Wales State Fisheries Atlantic salmon effort is now centred on Lake Jindabyne. Also, brook trout, *Salvelinus fontinalis* (Mitchill), have recently been liberated in some high-country tributaries of the Murray in New South Wales and are thought to have established themselves in some areas (New South Wales State Fisheries, pers. comm.).

TABLE 3
INTRODUCED FISH OF THE MURRAY-DARLING RIVER SYSTEM

Family	*Species*	*Common nam*
Salmonidae	*Salmo trutta* (Linnaeus)	Brown trout
	Salmo gairdneri (Richardson)	Rainbow trout
Percidae	*Perca fluviatilis* (Linnaeus)	European perc (Redfin)
Cyprinidae	*Cyprinus carpio* (Linnaeus)	European carp
	Carassius carassius (Linnaeus)	Crucian carp
	Carassius auratus (Linnaeus)	Goldfish
	Tinca tinca (Linnaeus)	Tench
	Rutilus rutilus (Linnaeus)	Roach
Poeciliidae	*Gambusia affinis* (Baird and Girard)	Mosquito fish

In the Murray-Darling Basin, both brown and rainbow trout typically occur in high-country rivers and streams, especially above 600 m altitude. However, where there is a rapid fall of cold water from high altitudes they are found down to below 300 m. Their range is extended further by the discharge of cold water from large water storages. Both species are found occasionally along the whole length of the Murrumbidgee, in the Murray downstream to beyond the border of South Australia, and as far downstream as Brewarrina on the Darling. The downstream limits of their range are controlled by high water temperatures and also, to some extent, lack of suitable spawning areas. However, liberations of fish from the State Fish Hatcheries of New South Wales and Victoria often maintain trout populations in marginal habitats. In general, in the Murray-Darling System trout occur above 600 m altitude in all of the main tributaries of the McIntyre, Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee and Murray (Weatherley & J. S. Lake 1967).

European perch are widespread and common throughout the major rivers to the west of the Great Dividing Range, except for most of the Darling. They are usually most abundant in still or sluggish water among or near weeds, but when floods occur they may be distributed uniformly throughout the rivers (Weatherley 1963, Weatherley & J. S. Lake 1967, Cadwallader 1977).

Tench have a widespread but discontinuous range in the Murray-Darling Basin, occurring mainly in relatively sluggish and weedy river stretches and in lakes. They are common in the swampy regions of the Lachlan River above its confluence with the Murrumbidgee. They do not usually occur in the headwater sections of rivers. According to Weatherley & J. S. Lake (1967), goldfish and crucian carp occur generally throughout the Murray-Darling Basin, though their distribution in high-country areas is rather patchy. They are usually found in the more sluggish rivers and in dams, shallow lakes and lagoons. European carp have been in Australia for many years (Stead 1929), but their spread throughout the Murray-Darling River System has occurred only recently (Wharton 1971). In about 1964-65 they spread from Lake Hawthorn near Mildura along the Murray into South Australia and towards Swan Hill, as well as into the Darling and Murrumbidgee. Their range is now extensive: they have been found in the Kiewa River, above Yarrawonga Weir, downstream as far as the mouth of the Murray and throughout inland New South Wales and into southern Queensland (Apps 1976). Weatherley and J. S. Lake (1967) reported that roach are rarely found in the Murray-Darling System, but they have been found recently in the Eildon Reservoir on the Goulburn River (Cadwallader & Rogan 1977).

Mosquito fish occur throughout the Murray-Darling System, but they are not usually found in the cooler waters of high-country streams; they also avoid rapid waters (Butcher 1967, Weatherley & J. S. Lake 1967).

With few exceptions, information on the effects of introduced fish on the native fish fauna is anecdotal and fragmentary, not only because so little is known about native fish, but also because the effects of introduced fish have been overshadowed by the effects of the great physical changes that have taken place in native fish habitats. There is much overseas evidence of the adverse effects of introduced fish on native fish, e.g. Miller (1961), Regier (1968), Zaret & Paine (1973), Zaret (1974) and Moyle (1976b), and *a priori* it must be assumed that the introduction of any new species will have repercussions as far as the native fauna is concerned. To date, the incessant liberation of trout by the State fisheries agencies of New South Wales and Victoria has been the most prevalent form of species pollution in the Murray-Darling River System. As in Tasmania and New Zealand, trout have been liberated into almost all waters thought to be suitable for them, but unfortunately in most instances little information is available on the composition of the native fauna before the first trout introductions were made.

Trout have fragmented the range of some species of galaxiids into a number of small isolated populations. For example, R. Frankenberg (1966) found that in the headwaters of the Kiewa River on the Bogong High Plains brown trout occupy the main body of the stream, while galaxiids are found only in situations inaccessible to trout, such as above waterfalls. A similar situation involving brown trout and *Galaxias olidus* was found in a recent survey of the Seven Creeks River System (Cadwallader unpublished data). In addition, during a survey of all major streams in the Lake Eucumbene catchment, Tilzey (1976) sampled one particular stream over a period which spanned an invasion by rainbow trout. In 1971 the stream contained only *G. olidus*; by 1974 the galaxiids had completely disappeared below a natural barrier to trout, but above the barrier the biomass and population structure of *G. olidus* had not changed greatly after 1971. Historical data for the catchment area suggested that the introduction and subsequent success of trout are primarily responsible for the present much fragmented galaxiid distribution. Similarly, McDowall (1968) concluded that, although data were not conclusive throughout New Zealand that trout are detrimental to stocks of native fish and other aquatics, 'it is clear that in some localities and for some species, there has been extinction or marked stock reduction of native forms associated with the presence of the introduced trout'.

In a summary of the 'scanty knowledge' of the relationships between the more important (from the angling point of view) indigenous and non-indigenous fish of Australia, Butcher (1967) reported that trout eat small Macquarie perch, trout cod and blackfish. There is also a great overlap in the diets of trout and of these three native species (McKeown 1934, Butcher 1945, Cadwallader unpublished data), whose ranges extend (or once extended) to many waters in which trout have been introduced. In addition to predation and competition for food, it is also likely that trout cod and trout compete for space on the stream bottom. Observations on the behaviour of young (1-6 months old) trout cod in aquaria (Cadwallader unpublished data) indicate that they establish well-defined territories among the boulders and pebbles on the substrate, similar to the territories described by Kalleberg (1958) for young trout.

The food requirements of European perch are similar to those of the larger native species, such as Murray cod and golden perch. In addition, this species is also a voracious predator on smaller fish (Butcher 1945). The annual Melbourne-marketed catches of European perch and 'Murray fish' from the Kerang lakes between 1919 and 1949 (Fig. 4) may perhaps reflect the actual relationships between this introduced competitor-predator and the native fish fauna of the area. Such data must be interpreted with caution, but it appears that when

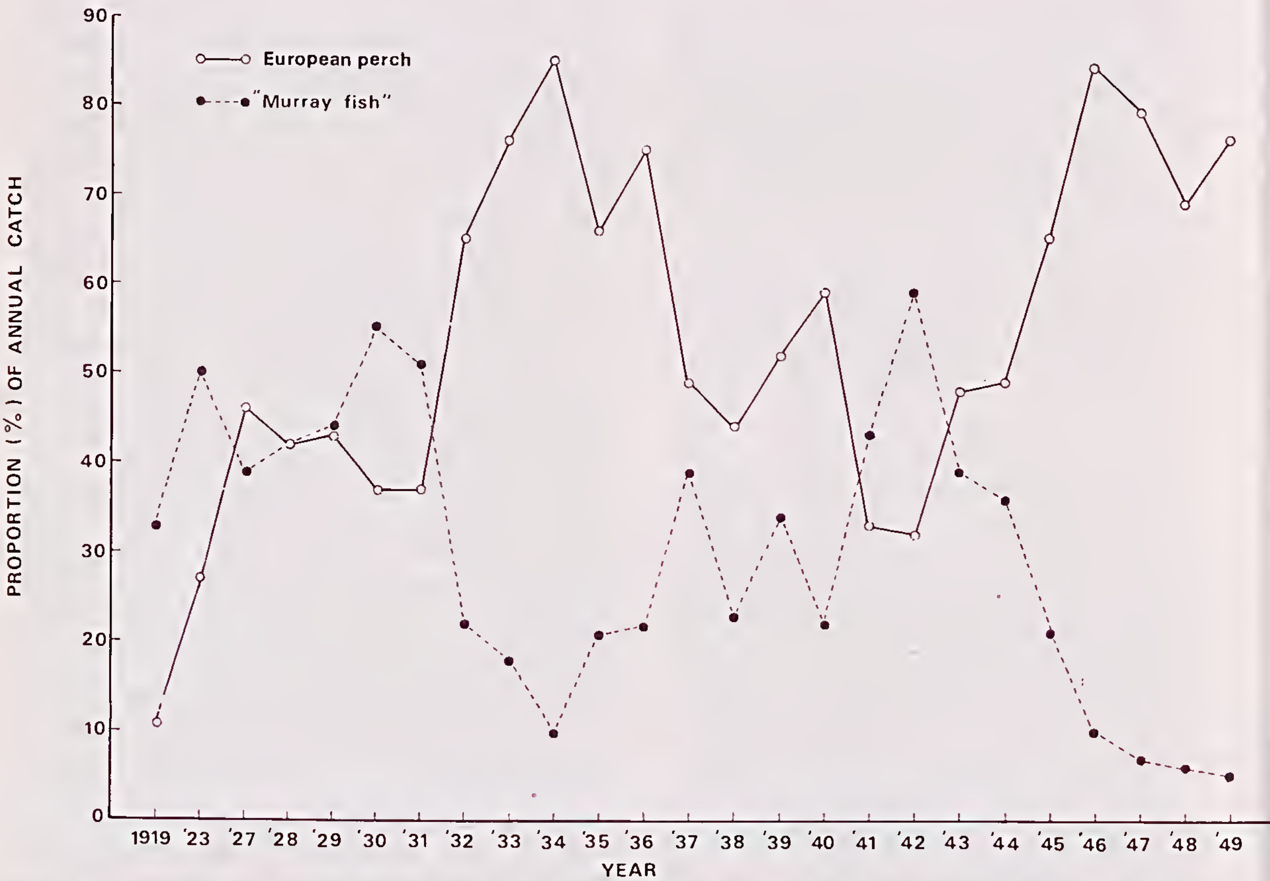

FIG. 4 — Proportion (%) of European perch and 'Murray fish' (includes all native fish, mainly silver perch, golden perch, Murray cod, bony bream and catfish, as well as *Carassius* spp.) in the annual Melbourne-marketed fish catch taken in the Kerang Lakes between 1919 and 1949. After Cadwallader (1977).

there was a large population of European perch the 'Murray fish' population was low and did not increase until the European perch population declined, and so on.

The diets of tench, roach, goldfish, crucian carp and European carp overlap those of native fish such as silver perch and, to a lesser extent, Macquarie perch (J. S. Lake 1959, Butcher 1967, Cadwallader & Rogan 1977, Cadwallader unpublished data). As well as feeding on the same foods as both native fish and some of the larger invertebrates which native fish ultimately feed on, European carp may also modify the environment (Butcher 1962). By their feeding and spawning behaviour they destroy weed beds, which provide shelter and food-producing areas for other fish. In addition, their feeding habits may increase the turbidity of the water and disrupt plant growth in warm, slow-flowing waters. In shallow lakes water quality deteriorates markedly and may not be restored until the carp are removed. On the other hand, in rivers and large deep lakes, the effects of carp may not be so pronounced and, in fact, some lakes can carry large populations of carp without showing any signs of deterioration in water quality (Apps 1976). Weatherley and J. S. Lake (1967) also point out that many rivers inhabited by native fish 'are by nature muddy', and that some native fish, such as catfish, do a lot of bottom grubbing, thereby also contributing to the turbidity.

Myers (1965) pointed out the dangers of introducing mosquito fish, *Gambusia affinis*, into areas where it does not occur naturally. He noted that almost everywhere that *Gambusia* had been introduced it had gradually eliminated most or all of the smaller native species of fish and had also often taken a heavy toll of the young of large fish species. In the Seven Creeks River System, the diet of *G. affinis* was found to be very similar to that of smelt (Cadwallader unpublished data). A related species, *Gambusia dominicensis* Regan, has apparently penetrated into water holes in central Australia, where it threatens the existence of the rare desert goby, *Chlamydogobius eremius* (Zeitz) (Connell 1974). Stephanides (1964) reported the wholesale destruction by *G. affinis* of the Entomostraca and aquatic insects of a small Corfu lake, and Hurlbert *et al.* (1972) found that in artificial ponds *G. affinis* greatly reduced the rotifer, crustacean and insect populations with a consequent extraordinary development of phytoplankton.

Apart from competition and predation by introduced fish on native species, the introduction of foreign fish diseases may have severe effects on native fish. It is extremely fortunate that until now many of the serious fish diseases do not appear to have been introduced, although intensive fish culture has not yet developed to the extent which would readily indicate their presence (Ashburner 1976). In the early days of fish introductions, eggs and fry were subjected to a relatively effective quarantine period because of the distance of Australia from the source of supply of these fish; diseased eggs and fry died at sea. With the advent of air transport the time factor has been eliminated and it is possible that diseases may have entered Australia in recent years. For example, the disease mycobacteriosis has recently been found in quinnat salmon, *Oncorhynchus tshawytscha* (Walbaum), imported from Oregon, U.S.A., in 1966 (Ashburner 1977).

The large number of fish species currently being imported into Australia as part of the aquarium fish trade (McKay 1977) also presents a serious threat to the native fish fauna of the Murray-Darling System.

OVERFISHING

Overfishing of native fish stocks by commercial fishermen has probably contributed to their decline in certain areas of the Murray-Darling System (Roughley 1951). In addition, in 1959 and 1960 the spawning migration of Macquarie perch from Eildon Reservoir into the inflowing Jamieson and Goulburn Rivers coincided with the opening of the angling season, and the total catch of Macquarie perch from these rivers during the opening week of each season was estimated at 2-3 tonnes of fish. Such catches must have had a deleterious effect on the Macquarie perch stocks, particularly in conjunction with the illegal fishing which is known to have occurred when the migration occurred in the closed season (Cadwallader & Rogan 1977).

In conclusion, although preservation of the natural aquatic environment received little or no consideration in the early planning for water conservation and land management (Wharton 1969), there is still scope in some areas for controlling or eliminating some of the factors which may further reduce the distribution and abundance of native fish, e.g. by adopting, where possible, water management practices that take into consideration the spawning requirements of native fish, by more rigid control of detrimental forestry and agricultural practices, by curtailing pollution, by preventing the introduction of new species, and by careful consideration of the implications of any further proposed changes to the environment. Considerable further work is required on the factors affecting the distribution and abundance of native fish, and the results of this work should be used for determining future river management policies.

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